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THERMAL AND PHYSIOLOGICAL RESPONSES OF BASIC UNDERWATER DEMOLITION/SEAL (BUD/S) STUDENTS TO A 5.5-MILE OPEN-OCEAN SWIM

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Thermal & Physiological Responses Of Basic Underwater Demolition/SEAL (BUD/S) Students to a 5.5-mile Open-ocean Swim

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SUMMARY

Problem.

Cold stress can compromise Naval Special Warfare (NSW) training and operations. The resulting cold strain and performance degradation can jeopardize mission success as well as operator safety. The selection and use of thermal protection equipment has been based on operational experience and passed on as "lessons learned." There is, however, a relative lack of objective data on the adequacy of thermal protection equipment in NSW scenarios.

Objective.

This study was performed to evaluate physiological and thermoregulatory responses of Basic Underwater Demolition/SEAL (BUD/S) students to a 5.5 mile open-ocean swim. Studies were conducted twice when the water temperature was similar, but different thermal protection ensembles were worn. Changes in core body (rectal) temperature were used as indicators of the adequacy of the thermal protection equipment.

Approach.

Anthropometric data (height, weight, and skinfold thicknesses for calculating percent body fat) were obtained. Prior to the swim, body weights were taken and core body temperatures were measured using flexible thermocouples inserted into the rectum 15 cm (6 in) beyond the anal sphincter. Subjects then donned the thermal protection ensemble and performed the swim. Upon completion of the swim, subjects had body weight and core body temperature remeasured.

Results.

Thirty-six Second Phase (Diving) students participated during a December 1991 (DEC) swim (water temperature = 13.9°C [57°F]). They averaged 6.6% body fat and dressed in whole body wet suits (9 mm [$^3/_8$ in]) with booties, hoods, masks, and fins. Mean swim time was 240.7 ± 23.6 minutes. The time delay between exiting the water and having core body temperature measured was 13.4 ± 2.2 minutes. Swimmers showed a mean ± SD core temperature drop of 0.6 ± 0.12°C (1.1 ± 0.2°F) and drop rate of -0.08 ± 0.09°C$\cdot$hr^{-1} (-0.14 ± 0.17°F$\cdot$hr^{-1}). The mean weight loss (dehydration due to diuresis) was 2.3 ± 0.1 kg (5.0 ± 0.2 lb), or 3% of body weight.

Swim time was correlated with temperature drop ($r = -0.47$; $p < 0.01$), but not weight loss or body fat. Twenty-four different students participated in an April 1992 (APR) swim (water temperature = 17.2°C [63°F]). The mean time between water exit and core temperature measurement was 19.6 ± 13.9 minutes. They had a mean of 6.7 ± 0.2% body fat and dressed in wet suit tops (9 mm [$^3/_8$ in]) with booties, hoods, masks, and fins. Mean swim time was 232.8 ± 12.6 minutes. These students had a mean core temperature change of -1.41 ± 0.78°C (-2.5 ± 1.4°F) and a drop rate of -0.36 ± 0.09°C·hr^{-1} (-0.65 ± 0.17°F·hr^{-1}). Mean weight loss was 1.5 ± 1.0 kg (3.3 ± 2.2 lb), or 2% of body weight. There were no significant correlations among the measured variables.

Conclusions.

Despite the warmer water temperatures in APR, students had greater core temperature drops and greater drop rates than in DEC. Additionally, three students had mildly hypothermic temperatures (≤ 35°C [95°F]) in APR, compared to one in DEC. Swim speed (and exposure times) were the same for the swims, suggesting that metabolic heat production was similar. Similarity of body fat suggests that subcutaneous insulation was the same. The difference in core temperature response is likely due to the thermal protection on the swimmers' legs; wet suit top in APR compared to full body wet suit in DEC. In DEC, the active musculature of the legs was covered, effectively reducing the body-to-water thermal gradient resulting in greater body heat conservation. These data suggest that the practice of selecting thermal protection equipment based on water temperature may not be the most appropriate for ensuring participant safety.

INTRODUCTION

Thermal stress can have a substantial negative impact on the performance of Naval Special Warfare (NSW) personnel during training and missions. This effect is especially evident during prolonged operations in cold water. Cold water is a particularly inhospitable environment. Heat conduction of water is 25 times that of air (Bullard & Rapp, 1970) causing loss of body heat two to four times faster in water than in air at the same temperature (Rennie, Covino, Howell, Song, Kang, & Hong, 1962). The rate of heat production by a swimmer and of body heat loss to the water are critical factors in core body temperature homeostasis (Webb, 1979). In cool and cold waters, the metabolic heat produced by swimming can be inadequate to counteract the large thermal drain imposed by the water. Although heat production is increased during exercise, heat loss is also increased. Reducing body heat loss to the water becomes critical for the prevention of hypothermia when metabolic heat production is less than heat loss.

In addition to compensatory physiological responses (e.g., cutaneous vasoconstriction), during severe or prolonged cold water immersion, adequate thermal protection must be achieved through engineering solutions (Bachrach, 1981, 1985). During NSW training exercises and operations, wet suits and dry suits are frequently employed during cool/cold water exposures. During prolonged (> 3 hrs) immersion, especially in cool or cold water (< 15.6°C [60°F]), wet suits may be insufficient protection against hypothermia.

The design characteristics and effectiveness of many passive thermal protection systems have been studied in detail (Brewster & Sterba, 1988; Nuckols, 1978; Virr, 1984), including attempts to replicate the field conditions in the laboratory (e.g., Doubt, Weinberg, Hesslink, & Ahlers, 1989). However, the performance of thermal protection equipment in the operational environment can differ substantially from immersion studies conducted in the laboratory (Steinman, Hayward, Nemiroff, & Kubilis, 1987). The ultimate purpose of any thermal protection system is to maintain adequate physiological function and performance of the diver. During military operations, there is the additional goal of maintaining mission capability. Participants at the 1991 NSW Thermal Protection Workshop (Doubt & Curley, 1992) concluded that there was a need for a comprehensive evaluation of the thermal protection equipment used by NSW operators in operationally relevant scenarios.

Students in Basic Underwater Demolition/SEAL (BUD/S) training at the Naval Special Warfare Center, Coronado, California, are required to perform a 5.5 mile open-ocean surface swim during Second Phase (Diving). Over the course of a year, water temperatures encountered during the swim can vary widely (10° to 25°C [50° to 77°F]). Students are exposed to these waters for periods of 3 to 6 hours, depending on their swim speed. Naval Special Warfare Center Instruction 1500.3B (Appendix A) mandates the use of thermal protection ensembles for swims over two miles, with the degree of protection dependent on the water temperature. When water temperatures are 15.6°C (60°F) or below, students must wear a full-body wet suit (top and bottom) with hood, booties, and gloves. Above 15.6°C (60°F), students wear only a wet suit top (shortie) with hood and booties.

Despite the mandated use of the thermal protection ensembles, cases of hypothermia (core body temperature < 35°C [95°F]) have occurred during the swims. Cases of mild hypothermia are typically identified by instructors monitoring the swimmers' behavior/performance from safety boats during the swim or on shore immediately thereafter. Once identified, the swimmer is treated in the clinic at the Naval Special Warfare Center by supervised active rewarming using head-out, limb-out warm-water immersion. Despite the ready availability of medical treatment facilities and constant supervision of the instructors, the actual number of swimmers that become mildly hypothermic during these swims is unknown since only those displaying overt impairment are identified.

As part of a larger program to evaluate the efficacy of thermal protection in current NSW operating environments (NSW Biomedical Task 2-90), Naval Health Research Center (NAVHLTHRSCHCEN) personnel monitored select thermal and metabolic responses of BUD/S students during two 5.5 mile swims. This study was conducted in conjunction with normal training at BUD/S, and constituted only limited additional risk to the participants.

METHODS

Subjects

A total of 60 BUD/S students volunteered to participate during two separate 5.5 mile open-ocean swims: 36 students in a December 1991 swim and 24 in an April 1992 swim. The physical characteristics of these students are summarized in Table 1.

Table 1. Physical characteristics[†] of students participating in two separate 5.5 mile open-ocean swims.

Swim Date	n	age	height		weight		body fat
		[yr]	[cm]	[in]	[kg]	[lb]	[%]
DEC 1991	36	22 (3)	180.1 (5.9)	70.9 (2.3)	80.0 (8.5)	176.0 (18.7)	6.7 (1.4)
APR 1992	24	23 (3)	178.3 (6.4)	70.2 (2.5)	77.3 (6.6)	170.1 (14.5)	6.6 (1.2)

[†] All values are means (SD).

Procedures

Approximately seven days prior to each swim, students were briefed on the purposes of the study and on the equipment and procedures to be employed. Students electing to participate signed an informed consent agreement approved by the NAVHLTHRSCHCEN's Committee for the Protection of Human Subjects.

Five days prior to the swim, each student's height, weight, and percent body fat was determined. Body fat was estimated from body density (Siri, 1956) and 7-site skinfold thickness (Jackson & Pollock, 1978). Each student recorded all foods and beverages consumed during the three days immediately preceding the swim. The diet records included detailed instructions for the proper recording of food/beverage type and portion size. A "baseline" blood sample was drawn from an antecubital vein (with tourniquet) approximately 24 hours prior to the estimated time of completion of the swim. Blood was collected in 15 mL EDTA test tubes, placed on ice, then refrigerated at 4°C for subsequent determination of plasma glucose concentration (YSI Model 1500 SPORT L-lactate analyzer, Yellow Springs Instrument Corp., Yellow Springs, OH). Subjects were at least 3.5 hours postprandial (after eating) at the time of the blood draw.

On the day of the swim, body weights were measured with students dressed in UDTs (shorts weighing approximately 0.5 kg [1.1 lb]) prior to donning the wet suits. Next, each student inserted a flexible, disposable rectal thermistor (Sher-I-Temp LTU/UC', Sheridan Catheter Corp., Argyle, NY) into the rectum approximately 15 cm (6 in) beyond the anal sphincter. To facilitate insertion to the proper depth, all probes had a small piece of adhesive

tape at the appropriate depth. The probe leads were then connected to a calibrated, battery-operated datalogger (SQ32-10YS/1hr Squirrel, Science Electronics, Dayton, OH) for display. When the temperature reading stabilized, core body temperatures were recorded. Students then returned to the dressing room, removed the probe, donned their thermal protection ensembles, and reported to the beach for the swim.

Each swimmer was paired with a partner of similar ability based on previous swim times. In December, students wore a full-body wet suit (9.5 mm [$^3/_8$ in] thickness) with hood, booties, fins, and mask. In April, students wore a wet suit top (9.5 mm [$^3/_8$ in] thickness) covering the torso and shoulders, with hood, booties, fins, and mask.

Students mustered in formation on the beach, then swam in pairs to a buoy outside the surf zone, approximately 100 m from the beach. The swimmers assembled at the buoy for the start of the massed swim. At the midpoint of the swim (2.75 miles), students were required to ingest approximately 1 L of a glucose polymer/electrolyte beverage (Exceed®, Ross Laboratories, Columbus, OH) containing 50 g of carbohydrates. During the swim, water temperature, wind, and surf conditions were monitored and recorded. Time of water entry, buoy-to-buoy swim time, water exit, and time from water exit until measurement of core body temperature were also recorded.

Immediately following the swim, in accordance with the training schedule, students returned to the beach and performed 40 pushups. Students then returned to the building where the preswim measurements were made, a distance of approximately 100 m (70 m over sand, 30 m over pavement). The students rapidly removed the thermal protection ensembles, toweled dry, inserted a rectal probe, and reported for recording body weight and core temperature, using the same techniques as before the swim. Each student then had a blood sample drawn from an antecubital vein (with tourniquet) into a 15 mL EDTA tube for subsequent determination of plasma glucose concentration.

Analyses

Diet records were analyzed using Nutritionist III software (Analytic Software, Salem, OR). Descriptive and inferential statistics tests were performed using SigmaStat statistical software (Jandel Scientific, San Rafael, CA). Group comparisons were performed using the Students' t-test and correlations calculated using the Pearson product-moment correlation coefficient. A

significance level of 0.05 was selected to evaluate the differences between means. All data are reported as mean (± SD).

RESULTS

Food/Fluid Intake

The two groups of students were not significantly different in any of the physical characteristics measured (Table 1). Table 2 summarizes the food and fluid intake reported by the students prior to the swims. Macronutrient constituents are reported both in grams and as a percent of total caloric intake.

Table 2. Average daily food and fluid intake of BUD/S students over three days prior to a 5.5 mile open-ocean swim.†

Swim Date	n	kcals	Protein [g]	Protein [% kcals]	Fat [g]	Fat [% kcals]	CHO [g]	CHO [% kcals]	Water [ℓ]
DEC 1991	29	4254 (1348)	166 (75)	15.5 (3.6)	172 (55)	36.7 (4.6)	511 (170)	47.8 (4.3)	7.0 (3.7)
APR 1992	21	4445 (1463)	220 (89)	19.9 (5.7)	159 (44)	33.1 (6.4)	533 (272)	47.0 (7.5)	5.3 (1.6)

† All values are mean (SD) daily average over three days.

December Swim

The water temperature was 13.0°C (57°F) for the December 1991 swim. The mean swim time was 240.7 (± 23.6) minutes, for an average swim speed of 1.14 (± 0.13) knots. During the swim, the mean core body temperature dropped 0.6°C (± 0.1°C) [1.1°F (± 0.2°F)], with one student (2.7% of December swimmers) exhibiting a hypothermic temperature (34.9°C [94.9°F]) after the swim. Table 3 summarizes the thermal responses of the students during this swim. Students' body weight decreased an average of 2.3 kg (± 0.1) [5.1 ± 0.2 lb] during the swim, or approximately 3% of preswim body weight. Body water lost during the swim probably resulted primarily from cold- and immersion-induced diuresis. Swim time was significantly correlated ($r = 0.47$; $p < 0.01$) with decrease in core body temperature, but not with body weight loss or % body fat. Mean plasma

glucose concentration after the swim (88.5 [± 12.6] mg·dL^{-1}) was nonsignificantly higher than baseline (85.6 [± 17.3] mg·dL^{-1}).

April Swim

During the April 1992 swim, the water temperature was 16.7°C (62°F). The mean swim time was 232.8 (± 12.6) minutes, for an average speed of 1.20 (± 0.07) knots. Mean core body temperature decreased 1.4°C (± 0.8°C) [1.8°F ± 0.2°F] following the swim. Three students (12.5% of April swimmers) exhibited hypothermic core body temperatures at the time of postswim temperature measurement. The thermal responses of swimmers during the April swim are summarized in Table 3. Weight loss during the swim averaged 1.5 (± 0.5) kg [3.2 ± 1.0 lb], or approximately 2% of preswim body weight. None of these variables were significantly intercorrelated. There was a nonsignificant decrease in plasma glucose concentration from a baseline value of 89.2 (± 7.5) mg·dL^{-1} to 77.0 (± 10.5) mg·dL^{-1} following the swim.

Table 3. Thermal responses of BUD/S students during two 5.5 mile open-ocean swims.

Date	Preswim Core Temperature (°F)			Postswim Core Temperature (°F)			Core Temperature Drop (°F)			Core Drop Rate (°F·hr^{-1} swim time)		
	high	low	mean (SD)	high	low	mean (SD)	greatest	least	mean (SD)	fastest	slowest	mean (SD)
DEC 1991	100.1	98.3	99.2 (0.5)	100.0	94.9	98.1 (1.5)	+1.0	-3.8	-1.1 (1.3)	-0.46	+0.17	-0.14 (0.17)
APR 1992	99.2	98.4	99.2 (0.4)	98.9	93.0	96.6 (1.4)	0.0	-5.7	-2.5 (1.4)	-1.42	0.00	-0.65 (0.17)

Comparison of December and April Swims

The students participating in the two swims did not differ significantly in physical characteristics (Table 1). Mean swim time in December (240.7 ± 23.6 minutes) was not significantly different from the April swim (232.8 ± 12.6 minutes). The time delay between exiting the water and having core body temperature measured was not significantly different between the December (13.4 ± 2.2 minutes) and April (19.6 ± 13.9 minutes) swims. December swimmers had a significantly ($p \leq 0.001$) greater body weight loss than April swimmers, and

consequently had a significantly ($p \leq 0.001$) greater degree of dehydration following the swim. Students in the April swim had a significantly ($p \leq 0.001$) greater overall core body temperature drop and drop rate than did the students in the December swim (Table 3). The change in blood glucose during the swim was significantly ($p \leq 0.001$) different in December (small rise) than in April (modest decline). Although the difference in blood glucose change was statistically significant, all values were within the physiologically normal range.

DISCUSSION

After completing a long cold water immersion, core body temperature typically shows an "afterdrop" (Savard, Cooper, Veale, & Malkinson, 1985; Giesbrecht & Bristow, 1992) or additional core cooling beyond that occurring during immersion. Therefore, it is possible that the core body temperature measured following these swims is lower than the actual temperature at the time the student exited the water. Nevertheless, the temperatures accurately reflect the thermal status of the swimmer shortly after water exit. During NSW operations, many missions consist of a wet insertion phase followed by a terrestrial action phase. In such scenarios, the NSW operator would most likely experience the lowest core body temperature in the land phase during afterdrop. The potential negative effects of an afterdrop in core temperature below 35°C are not known, but would depend on several factors including, but not limited to, the core temperature on water exit, the degree of afterdrop, air temperature, thermal protection equipment worn, and level of physical activity.

The thermal stress experienced by swimmers was greater during the April swim than during the December swim despite the higher water temperature. In April, students had a lower average core body temperature after the swim, a greater average core temperature drop, and a more rapid core temperature drop rate than for students in the December swim. In addition, a higher percentage of swimmers exhibited mildly hypothermic core temperatures in April than in December. The differences are most likely due to the thermal protection ensemble worn. During surface swimming at BUD/S, the legs are the most active large muscle mass, and thus are the major source of metabolic heat production and of conductive and convective heat loss (Toner, Sawka, & Pandolf, 1984). Although body fat can provide effective thermal insulation (Costill, Cahill, & Eddy, 1967; Toner, Sawka, Foley, & Pandolf, 1986), additional insulation is needed

to maintain core body temperature during immersion in very cold water or prolonged immersion in cool water. The similarities between the two groups in body fat, height and weight, initial core temperatures, and swim times (equalizing cutaneous/subcutaneous [skin and fat], exposure time, and metabolic heat production) suggest that the differences in temperature drop is attributable to the rate of heat loss. The insulation provided by working muscles is decreased during exercise as blood flow to the skin and muscles is increased, promoting core heat loss (Toner & McArdle, 1988). Additionally, during swimming, convective heat loss to the environment is increased by the water passing over the skin at a rate proportional to swim speed (Nadel, Holmer, Bergh, Åstrand, & Stolwijk, 1974; Witherspoon, Goldman, & Breckenridge, 1970). In December, swimmers wearing full-body wet suits likely benefitted from increased lower-body insulation. The greater insulation reduced the thermal gradient between the skin overlaying the exercising leg muscles and the water. The increased insulation reduced the heat flow from core body to water, despite the fact that the swim was performed in colder water.

The configuration of thermal protection equipment (e.g., insulative properties of the materials and body areas protected) and its application (e.g., tight fit or loose fit) play major roles in maintaining core body temperature during immersion (Steinman, et al., 1987; Wolff, Coleshaw, Newstead, & Keatinge, 1985). Studies of regional thermal protection during cold water immersion (e.g., Tipton & Goldman, 1987) suggest that thermal strain during the initial phases of immersion is greater when the limbs are exposed and the torso protected, than when the limbs are protected and the torso exposed. During head-out immersion at rest, heat loss from the limbs and the torso are approximately equal. However, during exercise while immersed, heat loss from the limbs increases more than heat loss from the torso (Ferretti, Veicsteinas, & Rennie, 1989). During surface swimming, a wet suit similar to the one worn during the 5.5 mile swims has an insulative value of 0.77 clo (Bradner, 1985). The December swimmers had this insulation evenly distributed over the trunk and the exercising limbs; and while the April swimmers had the same trunk insulation, wet suit insulation was absent over the working muscles of the legs. Although the water was colder during the December swim, the increased insulation over the limbs reduced heat flow from the core to the skin and subsequently to the water. Thus, the additional protection made the ensemble worn more effective in maintaining core body temperature of the swimmers. The incidence of hypothermia in both swims suggests that although the thermal protection used

during the December swim was more effective, the duration of the swims (approximately 4 hours each) may have been a contributing factor to the cases of hypothermia. It has been noted that although thermal protection systems that provide sufficient protection over short term exposures (< 2 h), they may not be adequate for longer-duration exposures in preventing "silent" (or progressive) hypothermia (Hayward & Keatinge, 1979).

CONCLUSIONS

The thermal protection mandated for use during the colder water (< 15.6°C [60°F]) December swim provided substantially greater thermal protection than the ensemble mandated for the warmer (water temperature > 15.6°C [60°F]) April swim. Further study under controlled conditions is needed to fully evaluate the efficacy of standard NSW thermal protection ensembles in reducing the probability of hypothermia during ocean swimming and in determining the performance capabilities of NSW personnel after such exposures. The use of task-oriented performance tests following the swims would provide more information on an operator's "mission capability" following a wet phase of a mission.

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APPENDIX A

WATER TEMPERATURE REGULATIONS FOR IMMERSION
AND WET SUIT PROTECTION FOR BUD/S

WATER TEMPERATURE REGULATIONS FOR IMMERSION AND WETSUIT PROTECTION

Table 1. **Water Immersion Time Limits**

ENERGY LEVEL CATEGORY/EVOLUTIONS	WATER IMMERSION LIMITS (minutes)	
	° F	Time
STATIC (immobile, or restricted movement)	< 60	10
Examples: SURF CONDITIONING, DOWNPROOFING (FLOATING)	60-65	15
	> 65	20
MODERATE (unrestricted movement)	> 60	20
Examples: WATER PT, DOWNPROOFING (TREADWATER)	60-65	25
	> 65	30
HIGHLY ACTIVE (high-energy tasks involving wet/dry periods, kapoks, boat crewing)	< 60	40
	60-65	50
Examples: LYON'S LOPE, RUN/SWIM/RUN, MAD MASH	> 65	60

Table 2. **DISTANCE/TEMPERATURE/PROTECTION REQUIREMENTS**

DISTANCE (Miles)	WATER TEMP (°F)	PROTECTION REQUIRED
2	> 64	NO WETSUIT (SKIN)
	63-64	HOOD
	< 63	WETSUIT TOP AND HOOD
>2	≥ 60	WETSUIT TOP AND HOOD
	< 60	FULL WETSUIT AND HOOD

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13. ABSTRACT (*Maximum 200 words*)

To evaluate thermal protection guidelines, we measured thermal responses of BUD/S students during 5.5-mile ocean swims. Data were collected when different thermal protection was mandated for students: 1) December (**DEC**; water temp=**13.9°C**; 9.5mm **full-body wet suit**, hood, booties; n=36) and 2) April (**APR**; water temp=**17.2°C**; 9.5mm **wet suit top**, hood, booties; n=24). **DEC** students (22±3 yr, 180±6 cm, 80.0±8.5 kg, 6.7±1.4 % body fat) and **APR** students (23±3 yr, 178±6 cm, 77.3±6.6 kg, 6.6±1.4 % body fat) did not differ significantly on physical characteristics. Mean ±SD swim time did not differ significantly between **DEC** (240.7±23.6 min) and **APR** (232.8±12.6 min). Mean ±SD rectal temperature drop (ΔT_R) and ΔT_R rate were significantly ($p<0.01$) greater in **APR** (-1.4±0.8°C and -0.36±0.19°C•hr^{-1}, respectively) than in **DEC** (-0.6±0.7°C and -0.14 ±0.17°C•hr^{-1}, respectively). Although mean swim time was not different, ΔT_R was significantly correlated with swim time ($r= 0.47$; $p<0.01$) for **DEC** but not for **APR**. No other thermal or performance variables were significantly intercorrelated for either group. Three **APR** students (13%) had hypothermic temperatures (≤ 35°C) after the swim, compared with one (3%) in **DEC**. It appears that with reduced thermal protection (**exercising legs exposed**), the **APR** swimmers experienced greater conductive and convective heat loss and had greater temperature drops despite the warmer water temperature.

14. SUBJECT TERMS Thermoregulatory; swimming; cold; thermal protection; special warfare

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